Hardness assurance methodology for analog single event transients

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Abstract

A methodology is presented for quantifying the effect of SETs in bipolar linear microcircuits on the response of modules or sub-systems where they are used. The methodology follows the format of the piece-part hardness assurance approach described in MIL-HDBK-814.

Outline

- Motivation
- Background
- MIL-HDBK-814 methdology
- Modification for ASETs
- ASET HA flow
- Conclusions

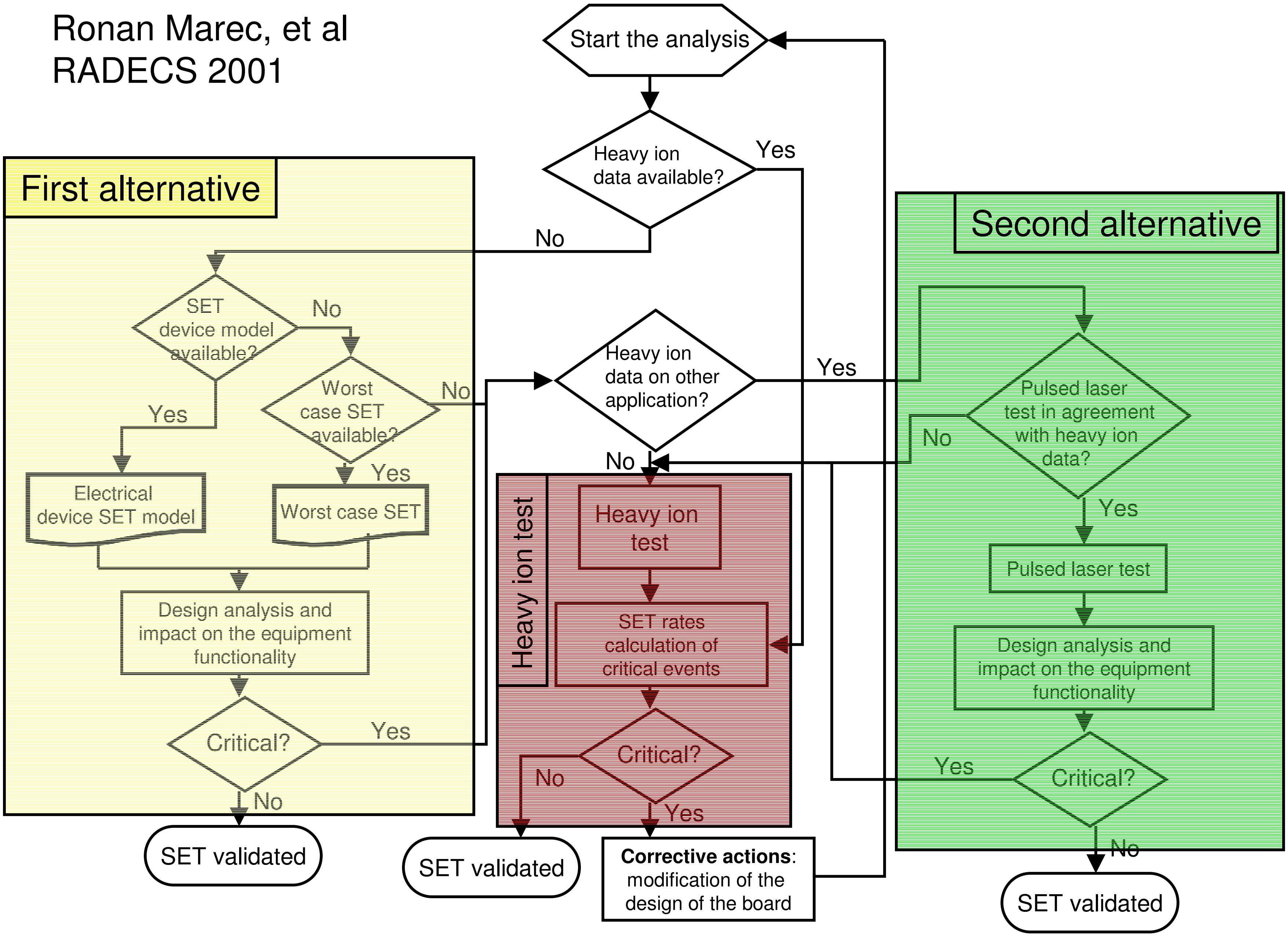
Motivation

Analog single event transients (ASETs) in bipolar linear circuits from heavy ion (HI) strikes can cause failure in space systems. A methodology is needed to address piece-part hardness assurance for this effect. The DTRA ASET program has developed a methodology which is presented here.

Background

- ASETs have been studied and characterized since 1993 (Koga, et al TNS 93)
- Many bipolar linear circuits are susceptible to ASETs as presented in a data compendium (Savage, et al IEEE NSREC Data Workshop 01)
- The DTRA ASET program has performed detailed investigations of the mechanisms of ASETs using extensive circuit simulations and heavy ion accelerator, micro-beam and laser testing
- A hardness assurance methodology for ASETs was presented by Marec, et al at RADECS 01
- A generic piece-part hardness assurance methodology was developed by DTRA in the 1980s through the SPWG and is detailed in Military Handbooks
- With minor modifications this methodology can be used for space system piece-parts including parts susceptible to ASETs

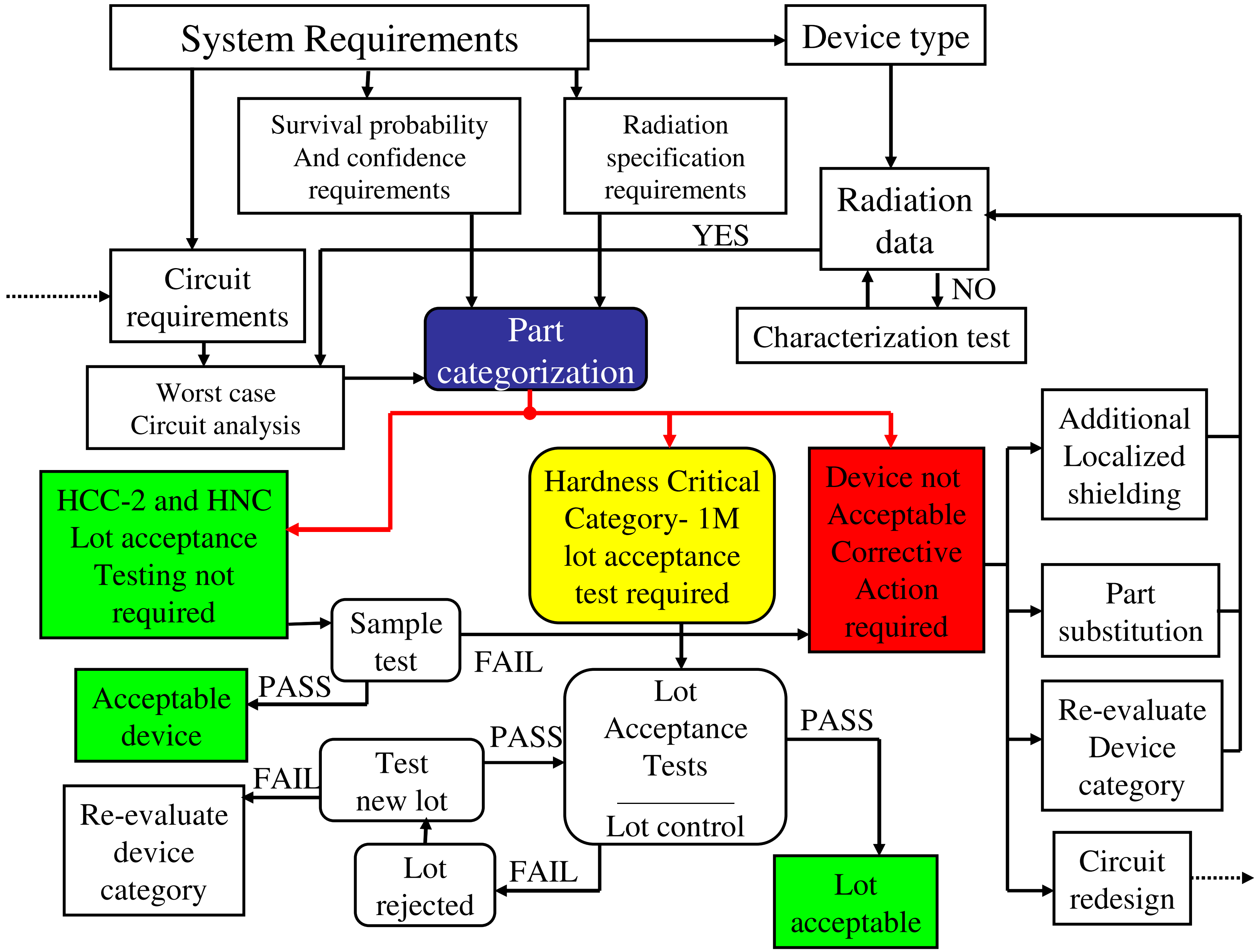
Ronan Marec, et al
RADECS 2001



Marec, et al method

- Approach uses a combination of worst case analysis and laser tests if HI data not available for specific application
- Worst case analysis based on maximum amplitude and pulse width of SET observed for different categories of part types
  - Rail to rail voltage amplitude
  - 10 μs max PW for comparators
  - 20 μs max PW for op amps
- 80-90 % of cases eliminated on basis of worst case analysis
- Recent data have shown that the maximum SET pulse width can far exceed to values used by Marec, et al invalidating this worst case analysis
  - OP293- up to 500 μs (Ladbury and Kim, NASA report 02)
  - RH1014- up to 280 μs (Larsson, et al RADECS 03)

Piece-part HA flow from MIL-HDBK-814



Categorization

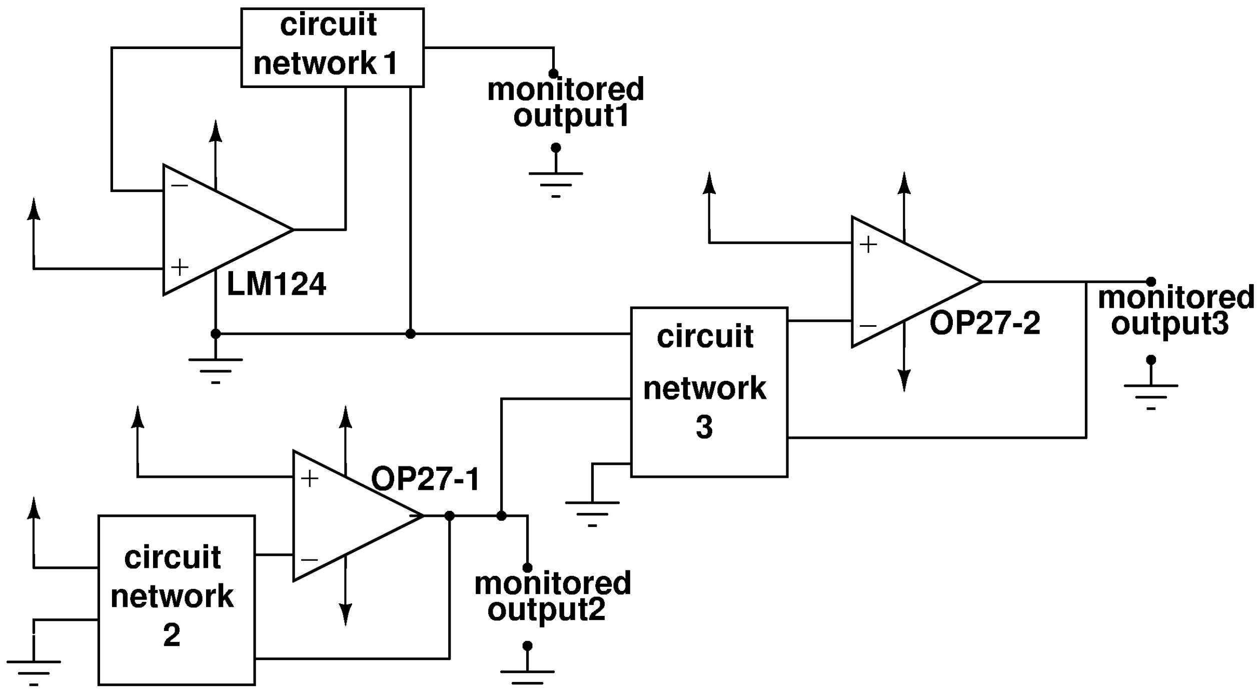
- Categorization based on radiation design margin- RDM
- RDM normally defined as mean radiation failure level of part divided by system radiation specification level
- Categories
  - Hardness non-critical (HNC)- no further tests or analysis
  - Hardness Critical Category (HCC)
    - HCC1-lot sample testing required
    - HCC2- periodic lot sample testing (does not apply to space systems)
  - Not acceptable- RDM must increase before part can be used
- Two methods for determining in which category a part is placed based on value of RDM
  - Design Margin breakpoint method- DMBP
  - Part Categorization Criterion- PCC

RDM for ASETs

- For ASETs the normal definition of RDM is not useful
- The definition of RDM proposed for ASETs is the ratio of maximum allowable error rate (specified by SPO) to mean part type error rate for system application and mission environment
- The system specified maximum allowable error rate requires a probability of survival, Ps, and a confidence level, C (often 0.9)
- The following information is required to determine the ASET RDM for a part
  - Definition of failure- minimum amplitude and pulse width of SET that would cause failure for the system application of the part
  - SET cross section vs LET for SET failure pulses
  - System mission parameters
  - Equivalent shielding between part and free field environment
  - Computer code to calculate error rate from mission parameters, device data and effective shielding

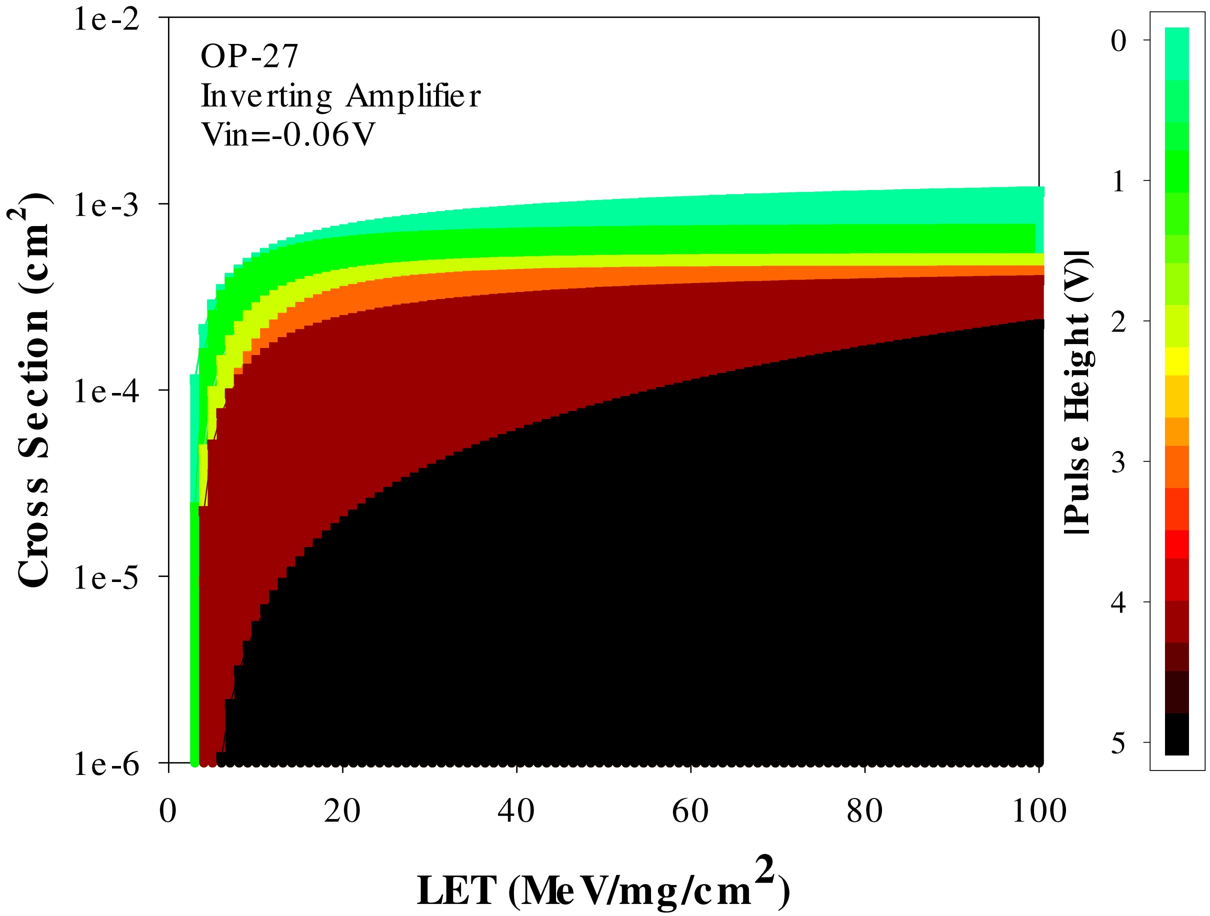
Example of failure definition (Boulghassoul, et al RADECS 03)

- Circuit for monitoring the power distribution in a satellite
- Bipolar circuits are LM124 and OP27-1 for current limiters and OP27-2 for current sensor
- Micro-models used to generate SET pulses and macro-models used for other circuits
- Failure occurs if transient at output 1 or 2 exceeds 1.25 V for 6 µs



ASET Data analysis

- SET cross sections vs. LET are mapped according to peak amplitude and pulse width
- Example shows contours for pulse amplitude
- Integrated with pulse width contour to determine failure σ vs. LET



Error rate calculations

- cosmic ray environment calculated with CRÈME
- integral LET spectrum (Z=1 to Z=92)
- interplanetary weather index M=3
- SET rate calculation using Weibull fit and PROFIT

orbit	km	inclination	without criteria 1event/X year	with criteria 1 event/X year
LEO	1400	84.7°	X= 15.6	X= 632
MEO	23600	0°	X= 34.6	X= 240
GEO	36000	56	X= 29.2	X= 191.7

HI data vs. laser data

- The laser has been shown to be a very effective tool for identifying the various SET waveforms that can be generated in a circuit
- If there are no HI data then the laser can be used to establish the worst case SET waveforms
- If the worst case SETs are below the failure SET then the part is HNC
- If the worst case SETs meet the failure criterion then HI data are required to establish the σ vs. LET response

Circuit simulations

- The DTRA ASET program has shown that SPICE circuit simulations can be used to accurately generate the SET response
- Very detailed circuit models (micro-models) are required and they must be validated with laser and HI data
- Validated SPICE micro-models can be used to explore worst case bias conditions and to generate SET waveforms for determining failure criteria of the application circuit
- SPICE macro-models can be used for determining the application circuit response for circuits not generating the SET

Categorization

- Design margin breakpoint- DMBP
  - Fixed breakpoints
  - Used for systems with moderate requirements
- Part Categorization Criteria- PCC
  - Based on statistics
  - Parametric distribution usually assumed (often lognormal)
- Sample must be representative of flight parts

RDM < 2	2 ≤ RDM ≤ 10(?)	10(?) < RDM
Unacceptable	HCC	HNC

RDM < 2	2 ≤ RDM ≤ PCC	PCC < RDM
Unacceptable	HCC	HNC

PCC = exp[KTL*sln(ER)]

KTL one sided tolerance factor
sln(ER)- sample standard deviation of the ln of the error rates

Unacceptable parts

- Substitute a different part type or the same part from a different manufacturer
- Increase the RDM
  - Re-evaluate shielding
  - Re-measure part with less conservative test conditions
  - Re-design application circuit to relax failure criterion
  - Reconsider maximum allowable error rate

Lot sample tests

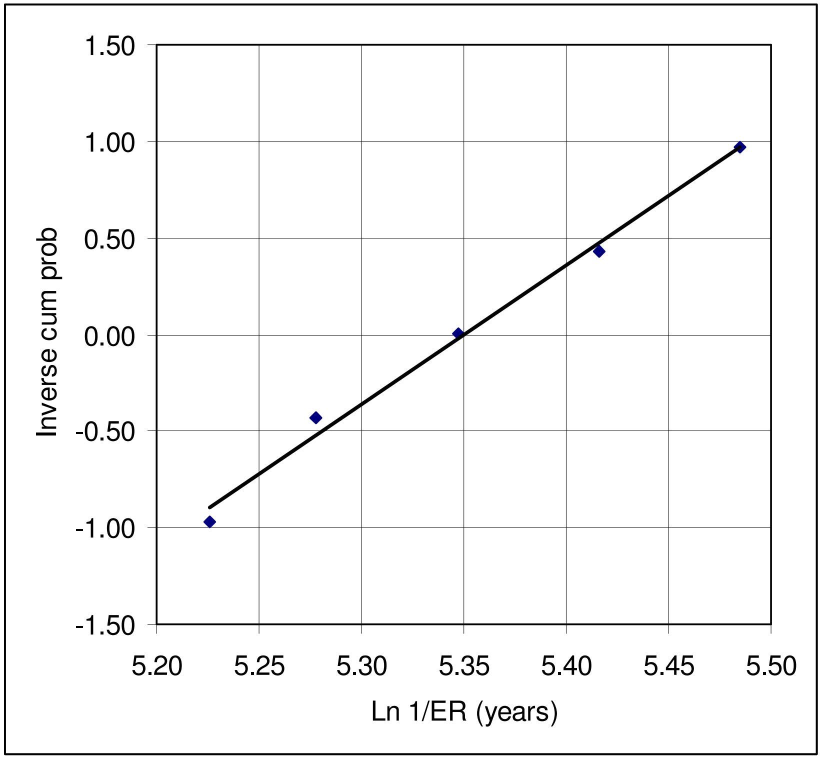
- All HCC parts must be given a radiation lot sample test (RLAT)
- There are two test methods for RLAT
  - Attributes- go/no-go test
  - Variables data
- Variables data test is required for ASET since an error rate must be determined

Example RLAT test

- **Assume max ER is 1/100 years for Ps=0.999 and C=0.9**
- **Assume that failure criteria is 1.25V for 6 μs**
- **Assume part is OP27, 5 samples, and data have been fit to a Weibull curve. ER has been calculated using the mission parameters and effective shielding**
- **Assume log normal distribution for ER**

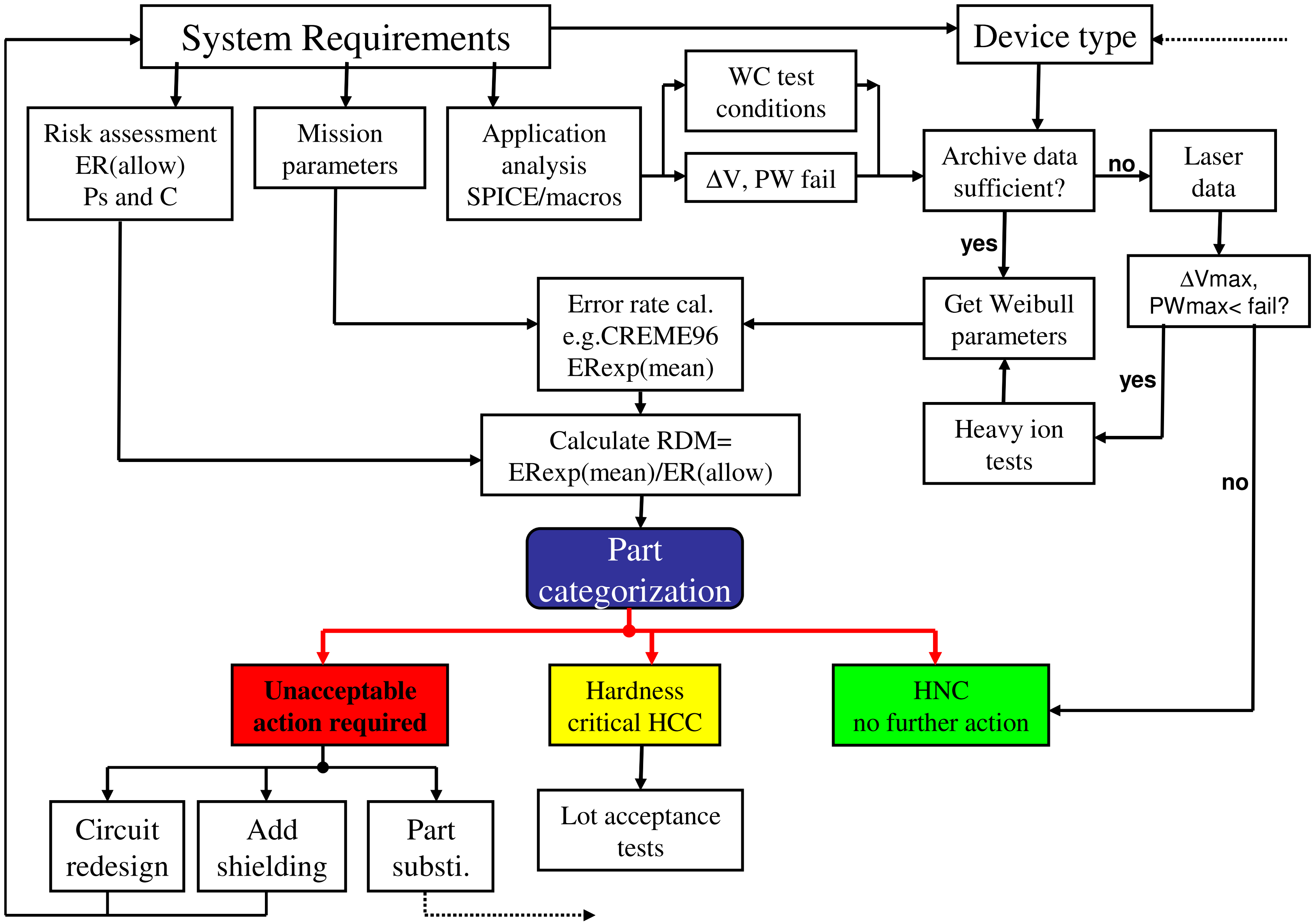
Sample #	1/ER (years)	ordered 1/ER	n/(N+1)	ln(1/ER)	NORMSINV
1	225	186	0.17	5.23	-0.97
2	210	196	0.33	5.28	-0.43
3	196	210	0.50	5.35	0.00
4	186	225	0.67	5.42	0.43
5	241	241	0.83	5.48	0.97
			mean	5.35	
			stdev	0.10	
			K_{TL}	6.11	

Inverse cumulative prob. of ln(1/ER)



Since exp(mean-stdev*K_{TL}) =112 years, the lot passes

Proposed ASET hardness assurance methodology



Acknowledgements

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